

A person wearing a blue uniform and a blue cap is using a backpack sprayer to spray a field. The sprayer is yellow and black. The person is holding a long nozzle and spraying a field of green and yellow plants. In the background, there are several people watching, including a woman in a floral dress and a man in a blue shirt. The scene is outdoors on a dirt path.

Module 1: Introduction to chemicals management

Most frequently used chemicals: are some chemicals better or safer than others?

© Mark Edwards /Still Pictures
Spraying mosquito breeding grounds to control malaria, Cameroon




MODULE AIMS:

The module aims at:

- Providing basic information on hazardous chemicals, their toxicity, including properties and characteristics, and their effects on human and environmental health, particularly for workers;
- Introducing the concepts and principles of green chemistry;

LEARNING OUTCOMES:

At the end of the session, the trainee will be familiar with:

- The terminology related to sound and sustainable management of chemicals;
 - The types of effects on human health and the environment, including routes of entry of chemicals into the body; and
 - The concept of green chemistry.
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UNIT 1: WHAT DO WE KNOW ABOUT CHEMICALS?

THIS UNIT WILL MAINLY ADDRESS THE FOLLOWING QUESTIONS:

1. What are hazardous substances?
 2. What do we know about them?
 3. Do we have enough knowledge of their effects?
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GETTING TO KNOW BASIC CHEMISTRY¹¹

Chemicals substances are everywhere. All **matter** (i.e. liquids, solids and gases) is made of **elements**. An element is the simplest form of matter that exists. At present, there are 106 different elements - including oxygen, nitrogen, carbon - and many other substances composed of atoms.

A single chemical element, standing alone, is a **pure substance**. When there is a combination of two or more elements, it is called a **compound** (for example, water (H₂O)).

At another level, a **mixture** is the name used to refer to a substance that contains more than one chemical element or compound, the separate constituencies of which, still retain their own properties. There are two different types of mixtures:

- **Homogenous mixtures**, known as **solutions**, which involve two or more substances (the **solutes**) dissolving into another substance (the **solvent**) (for example, salt or sugar dissolving in water, or gold into mercury); and
- **Heterogeneous mixtures**, known as **suspensions**, which are mixtures with definite, circumscribed composition (for example, granite, although a salad is probably the most typical example of this kind of mixture).

NAME, SURNAME AND "NICKNAME" OF CHEMICALS: HOW DO WE REFER TO THEM?

There are different ways to refer to and name a chemical. It can appear as the **chemical formula**, or it can be brought up by a **common name** that normally refers to the elements that make up the chemical compound (for example, hydrogen sulphide contains elements of hydrogen and sulphur).

¹¹ Chapter based on IPCS (International programme on chemical safety): Users' manual for the IPCS health and safety guides (1996), <http://www.inchem.org/documents/hsg/hsg/hsgguide.htm> (last accessed 14 April 2008)

It can also be called by its **trade name**. Producers and manufacturers often choose to give “trade” or commercial names to chemical compounds or mixtures to make them easier to remember.

There are different international identifications methods:

- The **CAS registry number**: each chemical is given a unique number by the Chemical Abstract Service (CAS), a division of the American Chemical Society. As of April 2008, there were 34,793,507 organic and inorganic substances, and 59,792,349 sequences in the CAS registry.¹²
- The **RTECS number**: is allocated by the Registry of Toxic Effects of Chemical Substances. It is a database of toxicity information on the health effects of the chemicals compiled from the open scientific literature. However, not all toxicity information is free or available.
- Another classification or numbering system involves the use of **UN numbers** or **UN IDs** that are used in the framework of international transport. They are four-digit numbers that identify dangerous goods, hazardous substances and articles (such as explosives, gases, flammable liquids, toxic substances, etc.).¹³

There are other nomenclature and referencing systems for classifying chemicals, including the **IUPAC** which has developed the International Chemical Identifier (InChI), and the **EC-No** and **EC#**, the latter ones being allocated by the Commission of the European Communities for commercially available chemical substances within the European Union mainly.

WHAT DO CHEMICALS LOOK LIKE?

Physical forms or “states”

Chemicals are present in different **physical forms**, with the main ones being:

- **Solid**. This form is the least likely to cause chemical poisoning. However, certain chemical solids can cause poisoning if they get onto your skin, or into food;
- **Dust**. Dust is made of tiny particles of solids. Exposure can be either from materials that normally exist in dust form (for example, bags of cement), or from work processes that create dust (for example, handling glass fibres that produce toxic dust);
- **Liquid**. Many hazardous substances, such as acids and solvents, are liquids when they are at normal temperature;

12 CAS Database Registry: <http://www.cas.org/cgi-bin/cas/regreport.pl> (last accessed 14 April 2008)

13 United Nations Economic Commission for Europe (UNECE) http://www.unece.org/trans/danger/publi/unrec/12_e.html (last accessed 14 April 2008)

- **Vapour.** This is the gas phase of a material that is found as a liquid under normal conditions. Tiny droplets of liquid which are suspended in the air are called mists; and
- **Gases.** Some chemical substances exist as a gas when they are at a normal temperature. However, some chemicals in liquid or solid form become gases when they are heated.

Other physical forms are **aerosols, fumes, smokes, and fogs.**

Chemicals can change forms or “states” depending on temperature and pressure. For instance, water is liquid between 0-100 degrees Celsius (°C). Above 100°C it is in a gaseous state (steam) and below 0°C it is ice, a solid state.

As a general rule, when the temperature of a solid is increased, it turns into a liquid (i.e. it melts). If the liquid is further heated, it boils and evaporates, generating smoke or fumes and turning into vapour or gas. If the surrounding pressure upon gases is increased without changes in temperature, they move from a gaseous state to a liquid one.

Substances can change from one physical form to another, depending upon temperature and pressure. It is crucial to be aware of the possible movement of chemicals between physical forms due to surrounding and external changes, since **some physical forms have a much greater negative impact than others.** A substance, which might not represent a risk¹⁴ in a solid state, for example, can become hazardous to a worker in a liquid or gaseous form.

Physical processes

They refer to the properties that chemicals have and which allows them to change from one form to another without involving a change in chemical composition. This happens through the following processes:

- The **boiling point**, which is the temperature at which a substance changes from liquid to gaseous state;
- The **melting point**, which is the temperature at which a substance changes from a solid to a liquid state;
- The **flash point** (open or closed cup), which describes the temperature at which a substance gives off enough vapour to form a mixture with air that can be ignited -causing it to burn- by a spark or flame;
- The **auto-ignition temperature**, which is the lowest temperature at which a substance burns without a spark or flame. To contrast these two types of properties, the flash point for gasoline (petrol) is <-40°C (-45°F), whereas for diesel it is at

14 It is important to distinguish risk from hazard. For a detailed explanation, see “Unit 3: Prevention, the best antidote to chemical exposure / Assessing hazards, risks and safety: safer handling, what else?”

>62°C (143°F); their respective auto-ignition temperatures are at 246°C (475°F) and 210°C (410°F).

The key physical properties are:

- **Solubility** in water designates the amount (by weight) of the substance that can dissolve in one litre of water to form a solution (homogenous mixture). This property is particularly relevant to possible water pollution and the potential impacts on aquatic organisms. In other words, high solubility compounds are normally a greater threat to aquatic organisms than low solubility compounds because they dissipate more quickly.
- **Insolubility** often refers to poorly soluble compounds, rather than to non-soluble compounds. In a stricter sense, **there are very few cases where absolutely no material dissolves.**

Other properties to mention are **vapour pressure, relative vapour density, flammability, octanol/water partition coefficient**, among others.

Physical hazards

The physico-chemical hazards encountered in the workplace level generally arise from **explosive, flammable, extremely flammable, highly flammable or oxidizing¹⁵ substances**. Often, of course, such substances will also present health hazards due to their toxicity.

Box 1.1. What are hazardous chemical substances?

A hazardous chemical substance is one that represents a risk for the safety and security of workers and the environment, due to:

- its physicochemical, chemical and toxicological **properties**;
- the form in which it is **used** (dust, aerosol, liquid...); and
- the form in which it is **found** in the workplace. For example, using water at room temperature might not be a risk, whereas if it is heated up to a 100°C, contact with that liquid or vapour could be very dangerous.

Source: *IPCS (International programme on chemical safety) (1996). "Users' manual for the IPCS health and safety guides"* <http://www.inchem.org/documents/hsg/hsg/hsgguide.htm> (last accessed 14 April 2008)

15 Strong oxidizing agents are often very reactive chemicals, and, in contact with combustible material such as paper, sawdust, fabrics or powdered metals, may form unstable mixtures, which constitute a risk of fire or explosion. A variety of substances can act as oxidizing agents. Oxygen on its own is a reasonably strong oxidizing agent, but other materials, such as fluorine, metal nitrates, potassium permanganate, hydrogen peroxide, sodium hypochlorite (bleach), or sodium dichromate are very effective.

WHY ARE CHEMICALS TOXIC? HOW TOXIC CAN A SUBSTANCE BE?

What is toxicology?

There is an array of toxic substances, whether manufactured (synthetic) chemicals like medicines, pesticides and solvents used in the industry, or substances occurring naturally in the environment.

They have the potential to cause harmful effects on human beings and the environment, referred to as **toxic** or **adverse effects**. Examples of toxic effects range from headaches, nausea, vomiting, or irritations, to cancer, alterations of the reproductive system, or death.

Nature is also capable of producing toxic substances which can also have adverse effects on human health and the environment: certain types of naturally occurring gases, or via fungi, viruses, bacteria, plants and animals like certain species of snakes, fishes or insects, among others. However, the far-reaching scope of injury caused by naturally produced elements does not come anywhere close to the devastating effects that some synthetic chemicals can have on human health and the environment.

Box 1.2. Types of toxic vectors

There are three types of toxic vectors: chemical, biological, and physical.

- **Chemical** vectors include inorganic substances such as lead, hydrofluoric acid, and chlorine gas; organic compounds such as methyl alcohol; most medications; and poisons from living organisms;
- **Biological** vectors include those bacteria and viruses that are able to induce disease in living organisms; and
- **Physical** vectors include elements that seldom come to mind as being "toxic": direct blows, concussions, sound and vibration, heat and cold, non-ionizing electromagnetic radiation such as infrared or visible light, and ionizing radiation such as X-rays.

This Manual will focus on chemical toxicity.

Source: Health and Protection Agency. Glossary. "Toxic Agent" <http://www.hpa.org.uk/webw/HPAweb&Page&HPAwebAutoListName/Page/1153846673536?p=1153846673536> (last accessed 14 April 2008)

- **Toxicology** is the science of adverse effects of chemical substances on living organisms. Even substances that are essential to our bodies, such as iron, can be toxic at high doses. Without enough iron, we would develop anaemia, but too much iron causes liver abnormalities.¹⁶
- **Ecotoxicology** is part of toxicology, and was defined by Truhaut in 1969, as “the branch of toxicology concerned with the study of toxic effects, caused by natural or synthetic pollutants, to the constituents of ecosystems, animal (including human), vegetable and microbial, in an integral context”. Throughout the Manual, the term toxicology refers also to ecotoxicology.¹⁷

Exposure to chemicals

For a chemical to exert an **effect**, there has first to be **exposure**. If there is no contact between a living organism and a chemical, no matter how toxic the chemical, the organism cannot possibly be harmed.

Occupational exposure is a concern of highest priority to workers as they may face significant exposure to chemicals in their daily jobs. Workers are at the frontline of occupational exposure during the different phases of production, storage, handling, transport, use and disposal of chemicals.

In addition, exposure may also occur in different and multiple ways (air, soil, water for drinking or irrigation in agriculture, etc.) through contaminated environments. Contamination can arise when waste are released into the environment, for example after industrial accidents or during industrial and agricultural processes. It is thus becoming increasingly obvious that **human health, environmental contamination and chemical exposure are closely linked**.

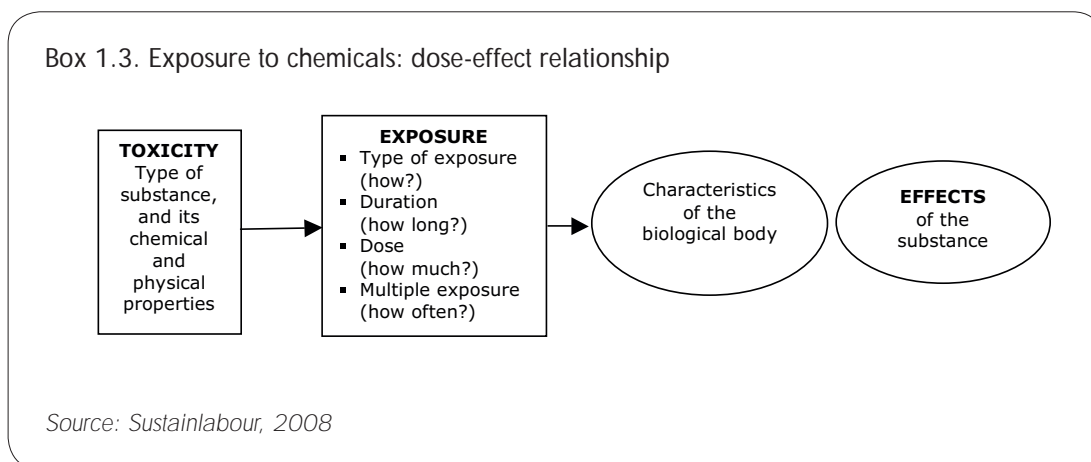
Although some chemicals are less harmful than others, their **combined effects** should be taken into account to assess the level of exposure and the potential consequences on human health and living organisms. The **dose** or **concentration** is another aspect to consider. For instance, a highly toxic substance can be extremely harmful even if only very small amounts are present in the body. Conversely, a substance of low toxicity will normally not produce any toxic effect unless the amount present in the body is significant.

There is a progression in severity of effects as the dose increases: it is the **dose-effect relationship**.

In addition to a chemical's dose, its toxicity also depends on how long exposure lasts, also known as the **duration of exposure**. Single exposure is referred to as **acute exposure**, while repeated exposure over a longer time is called **chronic exposure**.

16 International Occupational Safety and Health Information Centre (CIS), Chemical Safety Training Modules, What is toxicology?, ILO, <http://www.ilo.org/public/english/protection/safework/cis/products/safetytm/toxic.htm> (last accessed 14 April 2008)

17 Truhaut, R. (1977), “Eco-Toxicology - Objectives, Principles and Perspectives”, *Ecotoxicology and Environmental Safety*, vol. 1, no. 2, pp. 151-173.



Toxicological studies aim at assessing the adverse effects related to the different doses. To this end, they seek to establish the relationship between a determined dose and its effects on a variety of living organisms. The next section will introduce the major toxic effects that chemicals have on human health and the environment

The **exposure pathway**¹⁸ is an important notion that refers to the route a substance takes from its source (where the substance is first released) to its end point (where the substance ends: in the environment, on/inside the body), and how people come into contact with (or get exposed to) it.

An exposure pathway is defined by five elements:

- A source of contamination (such as factories which were closed down);
- An environmental medium and transport mechanism (such as movement through groundwater);
- A point of exposure (such as a private well);
- A route of exposure (eating, drinking, breathing, or touching); and
- A receptor population (people potentially or actually exposed).

When all five elements are present, the exposure pathway is termed "**completed exposure pathway**".

18 Agency for Toxic Substances and Disease Registry (ATSDR): Definition of exposure pathway, <http://www.atsdr.cdc.gov/glossary.html> G-D (last accessed 14 April 2008)

What are the toxic effects of chemicals on human health and the environment?

Hazardous chemicals are found in the tissues of nearly every person on Earth. Exposure to chemicals has resulted in several cancers and in a range of reproductive problems, including birth defects, development disorders and other diseases. The increasing number of cases and the constant exposure of individuals to a cocktail of chemicals have raised concern, particularly among workers.

Box 1.4. Classification of toxic effects of chemicals: definitions

Acute effect – The term acute means “of rapid onset and short duration” and, with reference to chemicals, usually means a short exposure with an immediate effect (24 hours or less). While an acute exposure can result in an acute effect, it can also result in a **chronic** disease, e.g. permanent brain damage can result from acute exposure to trialkyl tin compounds or from severe carbon monoxide poisoning;

Chronic effect – The term chronic means “of slow onset and long duration” and usually refers to repeated exposure with a long delay between the first exposure and the appearance of adverse health effects;

Acute and chronic effects – A substance may have both an acute and a chronic effect. For example, a single exposure to high levels of carbon disulfide can result in unconsciousness (acute effect), but repeated daily exposure for years at much lower concentrations may result in damage to the central and peripheral nervous system, as well as to the heart (chronic effects). Another example, perchloroethylene, known as the “universal solvent” for dry cleaning and other uses, can result in acute effects such as irritation and chronic ones such as cancer;

Reversible (temporary) effect – An effect that disappears if exposure to that chemical ceases. Contact dermatitis, headaches and nausea from exposure to solvents are examples of reversible effects;

Irreversible (permanent) effect – An effect that will have a lasting, damaging effect on the body, even if exposure to the chemical causing that effect ceases. Cancer caused by exposure to a chemical is an example of an irreversible effect;

Local effect – The harmful effect of a chemical at the point of contact or entry to the body, e.g. burns to the skin; and

Systemic effect – Occurs after the chemical has been absorbed and distributed from the entry point to other parts of the body.

It can be caused by a number of chemicals, including lead, beryllium, benzene, cadmium and mercury compounds.

Source: IPCS (International programme on chemical safety) (1996). “Users’ manual for the IPCS health and safety guides” <http://www.inchem.org/documents/hsg/hsg/hsgguide.htm> (last accessed 14 April 2008)

The terminology referring to the toxic effects of chemicals is complex and deserves particular attention. The terms “acute” and “chronic”, previously used to refer to **duration** of exposure, can also describe how long it takes for the **effect** of exposure to a certain chemical to appear, which is also very important data.

Below are listed some of the most toxic effects chemicals can have on humans, as well as on biological organisms.

- Concentrated solutions of strong acids (sulphuric acid for example), or alkalis (such as caustic soda), can cause chemical burns to the skin. A chemical that destroys or damages (burns) living tissue on contact is corrosive. A splash of a **corrosive** liquid in the eye, for example, can result in permanent damage to eyesight.
- When a chemical produces local annoyance, pain or inflammation of the skin, eyes, nose or lung tissue, it is called an **irritant**. For instance, a common substance like hypochlorite, also known as bleach, has a corrosive and irritant effect when applied to the skin.
- A chemical causing difficulties to breathe by interfering with oxygenation of body tissues, is an **asphyxiant**. There are two types of asphyxiation: **simple asphyxiation**, whereby oxygen in the air is replaced by a gas to a level at which it cannot sustain life (lack of oxygen); and **chemical asphyxiation**, whereby a direct chemical action interferes with the body's ability to transport and use oxygen. Examples of chemical asphyxiants include carbon monoxide and cyanides.

There are a number of reactions and effects caused by exposure to chemicals, which are highly damaging and irreversible. When these effects occur, the organism is so severely affected, that it is not possible to restore it into the original health state in which it was before exposure, thus resulting in a permanent change to the organism.

For example, chlorpyrifos, which is an insecticide on the market today, is used to kill insect pests by disrupting their nervous system; it is said to have an advantage over other products in that it is effective against a wide range of plant-eating insect pests. However, it has proved to cause immune system abnormalities to individuals, as well as to animals other than the targeted insect pests. Such a chemical can have a **sensitizing** or **immunotoxic** effect causing allergic reactions. A person who reacts to a chemical will experience a heightened reaction to it, even at a very low dose, whereas the chemical will not be harmful for the majority of individuals at the same dose. Any subsequent exposure to that substance – whether through skin contact or inhalation - represents a risk to the health of a person who has been sensitized to it.

Chemicals can also have a **carcinogenic** effect, meaning they cause cancer. Cancer is characterized by the manner in which abnormal cells in the body multiply and spread out of control. The key feature of cancer is the malignant or deadly way in which its cells crowd out sound/normal cells and interfere with the normal functioning of the body. For example, benzene, which is still used as a petrol additive or as an intermediate compound to manufacture other chemicals, has been classified by the International Agency for Research and Cancer (IARC) as carcinogen. For the record, one of benzene's early uses in the 19th and early-20th centuries was as an after-shave lotion because of its pleasant smell.

Box 1.5. Occupational cancer: the forgotten epidemic!

Little is heard about occupational cancer. At least one in every 10 cancers –and probably many more– are the result of preventable and predictable workplace exposure.

More people face risks of cancer in the workplace nowadays than at any other time in history. Regrettably, however, most of them are just not aware of it.

A cautious estimate by ILO puts the human toll from occupational cancer at over 600,000 deaths a year – one death every 52 seconds.

Source: International Metalworkers' Federation (2007) Occupational Cancer/Zero cancer – A Union Guide to prevention, <http://www.hazards.org/cancer/> (last accessed 19 December 2007)

Additional effects of chemicals include a **mutagen** effect, which causes permanent damages to the DNA (deoxyribonucleic acid) in a cell. DNA is a molecule that carries the genetic information controlling the growth and functioning of cells. DNA damage in the human egg or sperm may lead to reduced fertility, spontaneous abortion (miscarriage), birth defects and genetic diseases. As many mutations cause cancer, mutagens are typically also carcinogens.

Because some chemicals can adversely affect the reproductive capacity of women and men, and the un-born generations, they are said **toxic to reproduction**. They affect all phases of the reproductive cycle, as adverse effects on the developing organism can result from exposure before conception (either parent), during pregnancy, or between birth and the time of sexual maturation. Toluene belongs to that category; though, this product is largely used, especially as a common **solvent** to dissolve paints, paint thinners, chemical reactants, rubber, printing ink, adhesives and glues, lacquers, leather tanners, and disinfectants.

Endocrine disrupters are chemicals that alter functions of the hormonal system, consequently causing adverse health effects in women and men, and their descendents. The possible health effects include breast and prostate cancer, reduction of sperm quality, and modified hormone levels. The children of exposed women can suffer from precocious puberty, vaginal cancer, deformation of reproductive organs, among other serious problems.

There is growing scientific consensus that numerous industrial and agricultural chemicals have the ability to interfere with endocrine systems and hormonal activities of all animals including fish. One of the best-known effects is the feminizing of male fish. Some examples of substances known or suspected to be endocrine disrupting chemicals (EDCs) are pesticides as atrazine, 2,4-D, DDE, DDT, diazinon, diuron, endosulfan, fenthrothion, glyphosate,

lindane, or industrial chemicals or breakdown products such as bisphenol A, dioxins, nonylphenol, PCBs, some phthalates.¹⁹

These effects may appear at extremely low doses, generally below legally established limits of exposure. Another example involves bisphenol A, which is used to make plastic bottles and many other plastic products. Apart from its impact on workers, it has also proven to cause sex reversals in animals like the broad-snouted caiman - an alligator native to South America - and has also caused reproductive malformations in quail and chicken embryos. This substance is both toxic to reproduction and an endocrine disrupter.

Some chemicals can have adverse effects on the structure and function of, both the central nervous systems (brain and spinal cord) and peripheral nervous system, causing muscular weakness, a loss of sensation and motor control, tremors, cognitive alterations, and a dysfunction of the autonomic nervous system. These types of chemical are known as **neurotoxics**.

TPB is an acronym which refers to substances that are:

- **"T"oxic** for mammals and aquatic organisms;
- **"P"ersistent**, given that they remain in the environment for long periods of time, degrading very slowly; and
- **"B"io-accumulative** as they tend to accumulate in the body tissues of living organisms. For example, pesticides like aldrin, dieldrin and mirex.

Cocktail of chemicals: multiple exposure and combined effects

Workers seldom use a single chemical in their daily jobs. Most times, they manipulate or are surrounded by two or more chemicals, to which they might be exposed via dermal contact (through the skin), inhalation (through the respiratory tract, including the lungs) or ingestion (through the mouth).

In the same way, in their normal environment individuals are seldom exposed to a single substance. When two or more chemicals are in presence, they may interact with each other, which can alter the resulting toxicity. However, the resulting effect of chemical interactions can take different forms. Basically, the four types of combined effects chemicals that can have are:

- **Independent:** when the chemicals taken individually produce different effects or have different modes of action, and do not interfere with each other;
- **Additive:** when the combined effect is equal to the sum of the effects of each agent taken alone. For instance, organophosphate pesticides, such as dialiphos, naled and parathion are usually additive. Numerically it could be represented as $1 + 1 = 2$;

¹⁹ Briefing note on Fish and Endocrine Disrupters, WWF, (1998) <http://www.ngo.grida.no/wwfneap/Publication/briefings/Fish.pdf> (last accessed 19 December 2007)

- **Synergistic:** when the toxic effect resulting from the interaction is greater than the sum of individual effects. An example of increased risk is asbestos fibres combined with cigarette smoking: the risk of developing lung cancer after exposure to asbestos fibres is forty times greater for a smoker than for a non smoker. Numerically it could be represented as $1+1=4$; and
- **Antagonistic:** when the respective effects of two or more substances neutralize one another (e.g. the way an antidote reacts to a poison). However, this type of interaction does not happen very frequently. For example, if dimercaprol binds with various elements such as arsenic, mercury and lead, the toxic effect will be less than what could be expected for dimercaprol alone. Numerically it could be represented as $3-2=1$.

There is not much information available that can help predict the likely effects of the potential interactions between hazardous chemicals. To be safe, or at least safer, chemical cocktails should be avoided or reduced to the lowest possible level.



Avoid mixing several chemicals. The combination may result in very dangerous effects.

Differing reactions: hyper-susceptible groups

Each individual responds in a specific way to a chemical. Exposure to the same dose over a similar time period will thus induce different responses among different people. This principle also applies to all life on Earth.

In the workplace, workers exposed to similar concentrations of the same chemical, at the same worksite, will not necessarily exhibit the same symptoms. There may be various reasons to that, including:

- Gender: women, because of a greater relative proportion of body fat, may be more susceptible than men to harmful effects of solvents which accumulate in fat tissues, for instance;
- Age: children and the elderly are generally more susceptible to chemical hazards;
- Race: certain races may be genetically more vulnerable to certain chemical exposures;
- Lifestyle factors and nutritional situations may also have a considerable effect on the action of some compounds; and/or
- Individual variations: different individuals with similar characteristics such as gender, age, etc. may have different sensitivities.

Box 1.6. What is the “healthy worker effect”?

Occupational groups very often have lower total mortality than the general population as the latter includes people unable to work due to illness or disability. In other words, any group of workers is likely to be healthier than the population as a whole, a phenomenon known as the “healthy worker effect”.

Source: ILO (1998). *Encyclopaedia of occupational health and safety* <http://www.lhc.org.uk/members/pubs/books/chem/chedeaaa.htm> (last accessed 19 December 2007)

How is chemical toxicity determined?

There are two main sources of information on health effects resulting from exposure to chemicals. The more frequently used source consists of toxicity studies on laboratory animals. The second source consists of studies on human populations.

Laboratory animals are those that undergo tests to measure the toxicity of a chemical before people and animals are widely exposed to it. Different animal studies can be undertaken. Acute toxicity test (short-term) gives, for example, the **LD₅₀ (lethal dose)** and **LC₅₀ (lethal concentration)** indices of toxicity, which are two widely used indicators for toxicity.

LD₅₀ (lethal dose) refers to the amount of the substance that kills 50% of the test population of experimental animals when administered as a single dose. The LD₅₀ is usually expressed as the mass of substance administered per unit of mass of the subject, such as grams of substance per kilogram of body mass. LC₅₀ (lethal concentration), used for inhalation experiments, is the concentration of the chemical in air that kills 50% of the test animals in a given time (usually four hours).

In general, **the smaller the value, the more toxic the chemical**. The opposite is also true: the larger the value, the lower the toxicity. It is also important to know that **the actual LC₅₀ value may be different for a given chemical depending on the route of exposure (dermal, oral, or respiratory)**.

For example, if the LC₅₀ value for a dermal route of exposure rates a chemical as extremely toxic, then the skin should be protected when handling it, using clothing, gloves, etc. made of an appropriate chemical-resistant material. Alternatively, if the LC₅₀ value for a respiratory route of exposure indicates the chemical is relatively harmless, then respiratory protective equipment may not be necessary (as long as the oxygen concentration in the air is in the normal range - around 18%).

To compare the **toxic potency** or **intensity** of different chemicals, researchers must measure a common parameter. One way is to carry out **lethality tests (the LD₅₀ tests)** by measuring how much of a chemical is required to cause death. They are very crude indices of toxicity, which give a very rough or gross figure, and are undertaken in order to compare the lethal toxicity of different chemicals. These tests do not give adequate data on carcinogenicity, teratogenicity or reprotoxicity.

Many national and international bodies are now trying to modify or replace the LD_{50} and LC_{50} tests by simpler methods, such as the **fixed-dose procedure**, as fewer animals are involved. This requires only a small number of animals, and analysts can evaluate a chemical's toxicity without animals dying as the ultimate result.



Civil society groups have campaigned against LD_{50} testing on animals, in particular to protest against the use of these substances, which result in the slow and painful death of animals. Several countries, like the **UK**, have taken steps to ban the oral toxicity LD_{50} testing, and the **Organization for Economic Cooperation and Development** (OECD) abolished the requirement for the oral test in 2001.

The **lowest dose** that causes a toxic effect (**TDLo**), or the **Lethal Dose Low (LDLo)** are other sources of toxicity information. There are other animal studies undertaken on mutagenicity, reproductive tests, to name but a few examples.

Conclusions related to chemicals toxicity are not all based on laboratory tests. Human evidence is also a very important source of information, especially in the case of hazards and effects in the workplace (occupational health), where most information come from reviewing specific cases and situations.

Epidemiological studies are another important source of information, basing investigations on the health of a group of people to establish whether they are affected by the chemical to which they are exposed at work or via the environment.

Although epidemiological investigations provide the most reliable proof of the adverse effect of a given chemical, it also has obvious disadvantages. Few chemicals have been submitted to epidemiological investigations because these analyses are very expensive compared to other tests. In addition, validation of the results requires a large number of exposed workers, and above all, it does not really act as a prevention measure: many people would have already been exposed and suffered illness or death before the investigations could happen.

Another important concept is **threshold dose** or **threshold concentration**, which refers to the minimum dose required to produce detectable responses in a given group of population, for example workers. The **no-observed-effect-level (NOEL)** refers to the greatest dose of a chemical, which causes no detectable health effect. And the **lowest-observed-effect-level (LOEL)** refers to the lowest dose of a substance which causes a detectable health effect.

Is there a tolerable toxicity limit?

The question of trying to establish a threshold based on the toxicity of the substance is used as the basis to estimate other indicators, as for example, the **tolerable daily intake (TDI)**,

which is the daily intake of a chemical contaminant over a lifetime without appreciable health risk.

However, it is impossible to examine every situation that might lead to toxic effects, and therefore potential effects may be missed. Whether there is a threshold dose, below which there is no toxic effect or an acceptable exposure dose, is very controversial because of the nature of the indicators.

To be able to handle and benefit from the properties of a chemical safely, i.e. in a way and at doses which ensure that overall exposure of people and/or other organisms is kept below defined and tolerable limits, it is fundamental to know how poisonous or toxic it is.

However, the notion of "tolerable" limit is not a fixed standard. The perception of what is "tolerable" is clearly influenced by economic, environmental, social and political factors. In particular, it is closely linked to the probability of occurrence of several factors - including suffering, injuries or disease - and social acceptance of associated risks in comparison to expected benefits arising from the direct use of a chemical or as part of a productive process.

It is important to be familiar with the systems of classification of toxicology, as they are the basis for determining **occupational limit values**. However, the limit values might vary from one country to another.²⁰ In deciding what constitutes a tolerable exposure, it seems necessary to establish principles or guidelines for action. For example, it may be prudent and necessary to demand the elimination of certain substances from the workplace if they can significantly damage human health or the environment.



The "**black-list**" of substances for which elimination is a priority for trade unions includes carcinogenics, mutagens, reprotoxic agents, endocrine disrupters, sensitizers, neurotoxics, and toxic, persistent and bio-accumulative substances (TPB). For these chemicals, trade unions advocate. **No tolerance! Exposure should be zero.**

20 BGIA GESTIS International limit values for chemical agents, (2008) http://www.hvbg.de/e/bia/gestis/limit_values/index.html (last accessed 14 April 2007)

Box 1.7. The case of aldrin

This was a pesticide largely used in the 1950s, to kill soil insects such as termites and grasshoppers in order to protect crops such as corn and potatoes. However, it has proven to be a persistent organic pollutant (POP) with carcinogenic and mutagenic effects. As early as the 1970s, it was severely restricted and banned in several countries, and in 2004 the parties to the global Stockholm Convention on Persistent Organic Pollutants agreed to eliminate its production, use and release.

Source: *IPCS International Programme on Chemical Safety, Health and Safety (1989). "Aldrin and Dieldrin Health and Safety Guide". Guide No. 21, <http://www.inchem.org/documents/hsg/hsg/hsg021.htm> (last accessed 17 December 2007) and Stockholm Convention on Persistent Organic Pollutants <http://www.pops.int/>*

Safe use of chemicals in the workplace implies:

- **Availability of information:**

It is important that toxicological information through testing methods be made available, as the toxicity and effects on human health and the environment of many substances that are already commercialized are still unknown. It is important to remember that **absence of evidence of risk** is not the same thing as **evidence of absence of risk**. With precaution as a guiding principle, it is logical to demand "zero tolerance" for substances whose effects are not yet known. This is valid for new substances as well as existing ones which are already on the market.

- **Promoting a culture of prevention:**

Understanding toxicological information is very important for workers' safety as users. It is important to be familiar with the systems of classification of toxicology, as they constitute the basis for determining **occupational limit values**, and therefore building a precautionary approach to the use of chemicals in the workplace.

However, in addition to a lack of toxicological information for many substances, the toxicological results sometimes lead to different interpretations from one legal source to another. For example, formaldehyde, which is used as solvent and adhesive, is classified by the International Agency for Research on Cancer (IARC) in Group 1, which means "the agent (mixture), is carcinogenic to humans", while the European Union considers it to be part of Category 3 in its classification, which includes substances with possible carcinogenic effects to humans, but for which insufficient information is available to make a satisfactory assessment.

Therefore, prevention must always be the leading strategy. In decisions relating to chemical safety, the toxicity of a substance is less important than the risk associated with its use. It is fundamental to adopt prevention and control policies of hazards in the workplace. As part of that effort, the promotion of a safety culture should take into account the common belief that all accidents can be prevented.

In the next chapter titled Safe Use of Chemicals in the Workplace, elimination is the main objective. Yet, whenever possible - which is often the case - prevention measures need to be implemented. Prevention measures should focus first on the cause of emission:

1. Priority 1 - **Eliminate risks**: ensure less risky situations, through changes in the productive process or substitution of dangerous substances;
2. Priority 2 - **Reduce and control risks** by adopting measures at the source of the exposure such as isolation, aspiration, ventilation systems, and other actions; and
3. Priority 3 – **Workers' protection**, in case the risks are not fully eliminated, or properly reduced and controlled (as per priorities 1 and 2): the worker will be provided with individual protective equipment.

It is worth noting that some cases may require a combination of the three prevention measures above-mentioned.

When all these prevention measures cannot be taken, and the risk is not fully eliminated or at a minimally acceptable degree, technical evaluations in the form of tests to workers and the workplace environment are undertaken to compare the actual exposure in the workplace with threshold limit values (TLV).

Where TLV are exceeded, corrective measures should be demanded. TLV are thus good tools for practical action. However, exposure below the TLV does not fully guarantee safety, and prevention measures still need to be implemented. The preferred strategy should be first and foremost that of anticipating and preventing the release rather than relying on an after-the-fact approach based on remediation and treatment.

- **Calling for a proper regulation of chemicals:**

Often decisions are made by national authorities based only on scientific data or on the interests of specific economic groups. Stakeholders are not involved, while some of them, like workers and trade unions, are at the frontline of chemical exposure, and should thus have a real say on regulation of chemicals.

Given the severe risks associated with chemical contamination, channels need to be created to guarantee the participation of workers and trade unions, in decision making processes, as a democratic principle. It is essential that workers and trade unions, as well as stakeholders in general, develop and strengthen capacity to influence debates on critical chemicals-related issues, including on the definition of what constitutes an injury or an adverse effect, of what is socially and environmentally acceptable or not.

More information about the chemical regulatory frameworks is provided in the third module of this Manual.

Box 1.8. Asbestos: the world's biggest industrial killer ever!

Workers and trade unions, have been long struggling to raise awareness on the risks and effects posed by the use of asbestos. Used massively as a natural mineral fibre in construction to insulate materials, in protective carpets and clothes due to its heat, electrical and chemical resistance. Asbestos has caused hundreds of thousands of deaths and illnesses, mainly among workers who handle it.

In June 2005, Global Unions launched its campaign for a "world ban of asbestos" at the ILO conference. However, despite the evidence, the vast amount of information available concerning deaths due to asbestos (at least 100,000 people in the world every year- one person every five minutes), and the resulting costs to society, it is still being used in some countries.

In recognition of these effects, asbestos bans are spreading, despite the offensive by the asbestos industry.

Source: Based on Hazards Magazine. Section Asbestos <http://www.hazards.org/asbestos/>

UNIT 2: PAINFUL, DEADLY ENCOUNTERS WITH POISONS

THIS UNIT WILL ADDRESS THE FOLLOWING QUESTIONS:

1. What are the effects of hazardous chemicals on human health? How does the body process them?
 2. What are the effects of hazardous chemicals on the environment? How does the environment process them?
-

WORKERS AND HAZARDOUS SUBSTANCES: A PERILOUS RELATIONSHIP!

Routes of exposure

Chemicals can enter the human body and other living organisms through a number of different pathways, known as “**routes of exposure**”; each pathway may react differently to the toxicity of a chemical. The type of route of exposure is thus critically important in determining how harmful a chemical can be.

The four major routes of exposure are: penetration through the skin or **dermal absorption**, through the respiratory tract and especially the lungs or by **inhalation**, through the digestive tract or by **ingestion**, and through the **eyes**.

The most common forms of occupational exposure are the inhalation of gases, vapours or airborne particles resulting in penetration through the lungs, and dermal contact, especially with liquids, which can be easily absorbed through the skin. The ingestion of poisons is common where general hygiene conditions are poor.

- **Inhalation: respiratory tract, lungs**

The lung is a common route of exposure. Unlike the skin, lung tissue is not a very protective barrier against chemical exposure. **In industry, inhalation is the most significant route of exposure.**

The substances irritate the mucous membrane of the upper respiratory tract and respiratory passages within the lungs. Thus, **the occurrence of irritation may indicate the presence of toxic chemicals.** However, certain gases or vapours do not induce any irritation and, when unnoticed, penetrate deeply into the body through the lungs where they may cause injuries, or even reach the bloodstream.

The entry of dust particles into the body depends on their size and solubility. The bigger they are, the more difficult it is for them to penetrate.



Exercise extreme caution with chemicals in the form of vapour, fumes, dust or gas, as they can easily enter the body through breathing.

- **Dermal absorption: skin contact**

Chemicals that pass through the skin are nearly always in a liquid form. Dusts, gases or vapours do not generally pass through the skin unless they are first dissolved in moisture at the surface of the skin. Chemicals that can dissolve easily in fats (lipids) are much more likely to penetrate the skin than chemicals that are soluble in water.

However, gaseous and solid chemicals can also pass through the skin: for example, highly toxic gases such as sarin and parathion, penetrate the skin without causing overt damage. If the skin is damaged by cuts or abrasions, or diseased, chemicals (including in a solid form) may penetrate easily and even more quickly into the body.

- **Ingestion: digestive tract, mouth**

Ingestion is another way in which chemical substances can enter the body. Eating at the workstation, where food and drink may be contaminated by vapours in the air, or smoking with contaminated hands, should be strictly prohibited. Besides, chemical substances can be ingested when inhaling particles through the throat, since they can be swallowed and pass both into the digestive system and the lungs.



Watch out while eating and drinking at your workstation! You may be introducing hazardous chemicals into your digestive system, because the substance may be coating the food or eating utensils.

- **Absorption through the eyes**

Any chemical, in the form of a liquid, dust, vapour, gas, aerosol or mist can enter the eyes. It is common to incur eye splashes or eye contamination due to exposure to chemicals in the workplace. Small amounts of chemicals can enter the eye by dissolving in the liquid surrounding the eye. The eyes are richly supplied with blood vessels, into which many chemicals can pass after penetrating the outer tissues. The eye may be damaged in the process, depending on whether the chemical is corrosive or not.

The different mucous membranes in the body – in the mouth, gastrointestinal tract, nose, vagina, etc. – can also be easy ways for the chemicals to enter the body.

How are chemicals processed within the body?

When a chemical enters the human body or any living organism, it goes through different processes. It is **transported** into different parts of the body where it can be **metabolized** (transformed), **accumulated** (stored) and/or **excreted** (expelled).

- **Metabolizing** is the process by which the body renders an alien chemical more easily extractable and/or less toxic. For most chemicals, the liver is the main site of transformation, but other organs such as the kidneys are also capable of metabolizing chemicals, sometimes into a resulting product that is also toxic.
- **Excretion** is the process by which unwanted chemicals are removed from the body, for example, by exiting through urine. However, these substances may cause damage to internal organs prior to excretion.

Chemicals that undergo a slow metabolism or excretion are often stored in various tissues inside the body. Sustained exposure may increase the amount of chemical present in tissues. Chemicals that are stored in this way are said to **accumulate**.

Adverse effects of chemicals on humans

The toxic effect of hazardous substances is not the same in all organs.

"A **local effect** refers to an adverse health effect that takes place at the point or area of contact. The site may be skin, mucous membranes, the respiratory tract, gastrointestinal system, eyes, etc.

Systemic effect refers to an adverse health effect that takes place at a location distant from the body's initial point of contact and presupposes absorption has taken place. Substances with systemic effects often have "target organs" in which they accumulate and exert their toxic effect."²¹

The central nervous system is the target organ of toxicity most frequently involved in systemic effects. The blood circulation system, liver, kidneys, lungs and skin follow in frequency of systemic effects. Muscle and bones are target organs for a few substances, causing for example degenerative osteoarthritis, osteoporosis.

- **Skin** is the largest organ in the human body. It provides a protective cover to the body but can fail to do so if the toxic load is overwhelming. A number of substances can penetrate healthy intact skins and pass into the blood stream. Phenol is a substance that can ultimately result in death after exposure and penetration through the skin. The vast majority of work-related skin diseases are contact eczemas, irritation and inflammation. This condition can be either a non-allergic or allergic reaction to chemical substances. Examples of common contact sensitizers are several colorants and dyes, metals such as nickel and its salts, chromium and

21 Chem Safe: Local vs Systemic Health Effects
<http://learn.caim.yale.edu/chemsafe/references/localvs.html>

cobalt salts, organomercuric compounds, the monomers of a number of acrylates and methacrylates, rubber additives and pesticides. In practice chemical skin injury is also influenced by environmental factors such as humidity and heat;

- **Lungs** are the major routes through which toxic substances found in the workplace enter the body. It is also the first organ to be affected by dusts, metal fumes, solvent vapours and corrosive gases. Allergic reactions may be caused by substances such as cotton dust, TDI (toluene diisocyanate, used in the manufacture of polyurethane plastics), and MIC (methylisocyanate, used in the production of carbaryl insecticide). Exposure to silica (quartz) or asbestos dust cause pneumoconiosis or lung cancer.²² Other substances, such as formaldehyde, sulphur dioxide, nitrogen oxides and acid mists may cause irritation and reduce the breathing capacity;
- The **nervous system** is sensitive to the hazardous effects of organic solvents. Some metals can affect the nervous system, especially heavy metals such as lead, mercury and manganese. Organophosphate insecticides such as malathion and parathion interfere severely with the transmission of information in the nervous system, leading to muscular weakness, paralysis or sometimes death. Because it is the nervous system, almost any of the many functions it controls can be inhibited by neurotoxicants - speech, sight, memory, muscle strength and coordination for example;
- The **circulatory system** is a target for solvents. Blood cells are mainly produced in the bone marrow. For example, when benzene affects the bone marrow, the first signs are mutations in the blood cells called lymphocytes. Lead and its compounds are other classic examples of chemicals toxic to the blood system. Chronic lead poisoning may result in reduced ability of the blood to distribute oxygen through the body, a condition known as anaemia;
- The **liver** is the largest of all internal organs and has several important functions. It is the body's "purification plant" which breaks down substances unwanted in the blood. As the liver shows a considerable reserve capacity, symptoms of liver disorder appear only in serious diseases. Solvents such as carbon tetrachloride, chloroform and vinyl chloride, as well as alcohol, are hazardous to the liver;
- The **kidneys** are part of the body's urinary system. Their main function is to excrete the waste products transported by the blood from various organs and ensuring that body fluids contain an adequate blend of various vital salts. They also maintain the acidity of the blood at a constant level. Solvents may irritate and impair kidneys' function. Carbon tetrachloride is the most hazardous to the kidneys. Turpentine in large quantities can also prove harmful: "painter's kidney" is a well-known condition related to occupational exposure. Lead and cadmium are also common kidney-damaging substances; and
- The **immune system** is a highly sophisticated defense system that protects the body from invading organisms, tumour cells and external agents. Immunotoxicants can have three different effects on the immune system: they can suppress the immune

²² Respiratory diseases from exposure to asbestos include asbestosis, lung cancer and mesothelioma.

system; make it hypersensitive, which causes allergies; or they can cause the immune system to attack its host, which is known as autoimmunity.

As indicated in the previous section, exposure to hazardous substances can also affect the male and female **reproductive systems** as well as have a **genetic impact, raising the possibility of transmission to descendents**.

THE ENVIRONMENT AND HAZARDOUS SUBSTANCES: MORE THAN JUST A DIFFICULT RELATIONSHIP

Chemical products have played a very important role in the development of modern societies. Indeed, they have offered immense benefits to humankind and a significant improvement in people's quality of lives. However, the accelerated proliferation of synthetic chemical substances since the Industrial Revolution also had devastating impacts on the environment, which cannot be ignored.

The chemical industry is not the only source of emission of chemical substances into the environment. Among other emitters and users are agriculture, transport, mining, metallurgy, and fuel refining, for example.

Chemical substances impact the environment in varied and complex ways. Overall, they contaminate the air, soil and water. Their persistence over time, the manner in which they are displaced and how they accumulate within organisms determine the hazard and the effects of chemical substances on the environment and human beings.

The contamination of the environment can occur by the "uncontrolled" release -be it intentional or not- of a chemical substance in the form of dust, fume, liquid or gas, due to mismanagement, sub-standard installations or "accidents". Nevertheless, contamination often happens because the dangers of some chemicals and their effects on the environment and human health are still unknown. This is why those chemicals are legally emitted into the environment.

Experience has shown that many chemical products that, at some point, have been promoted as innocuous to human health or the environment, have later proven to cause serious damage not only to those that are directly exposed to the said toxic substances -either during production process or use- but also to those who may have been exposed to them indirectly.

Water, soil and air are essential elements for the survival of human beings. The links between contamination of nature and human health are direct and well-known. Ecosystems and organisms have a determined capacity of absorption and recovery, which is not unlimited. The constant and growing pressure on nature has reduced its responsive capabilities to face environmental crises that might challenge the very reproduction capacity of our society.

A variety of technological, human, legal and financial means exist to control, protect and repair some of the environmental damages. Yet, the actual potential varies greatly among countries and regions -the poorer countries being usually more exposed. The global economic context, the production model and the associated consumption pattern drive

the most aggressive industries both to the environment and their own workers towards developing countries. The productive structure, and the lack of environmental and labour regulations make those countries comparatively convenient opportunities for big international economic interests. The same occurs with the final disposal of chemicals and toxic waste or the outsourcing of some highly contaminating recycling activities.

Over the years, workers and labour organizations have retained an important body of knowledge and developed the abilities to act and resolve specific problems linked to chemical exposure in the workplace. Furthermore, those abilities need to be further developed and reinforced in order to incorporate new visions that go beyond the workplace and fully take into account the complexity of the problem in all its dimensions.

The involvement of workers and labour organizations in the management of chemicals and their impact on the environment is fundamental, primarily because it opens the debate about what model and what forms of production and consumption we want. Nevertheless, it is a huge challenge for the labour sector - that already struggles daily against repeated threats to labour, social and human rights –a challenge that must be addressed decisively, as the very continuity of life on Earth depends upon it.

Origins of chemical pollution of the environment

As a result of economic activity, many chemicals are released into the environment. They are not only generated by the chemical industry, but also by other sectors -such as agriculture, car manufacturing, construction, energy production, extraction of fossil resources and minerals, metallurgy, pharmaceuticals, textile and transport, among others- which contribute significantly.

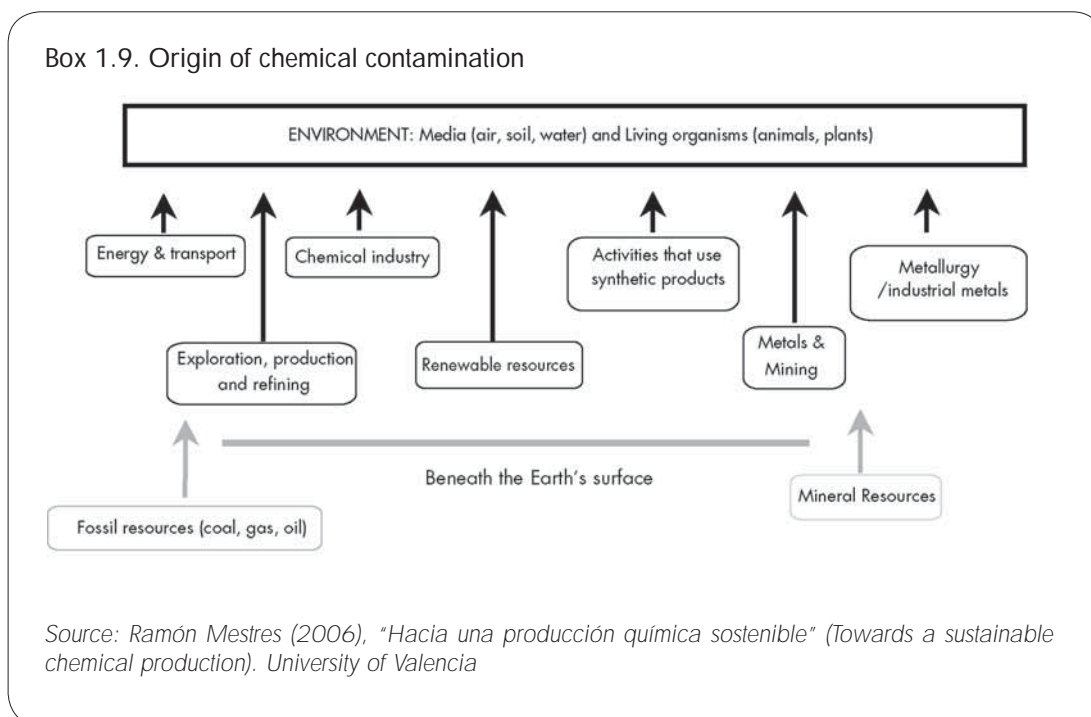
Almost all industrial activities generate contaminating substances such as mining (mine drains and leachate waters), waste removal (leachate landfills, land and sea refuse removal), aquaculture and mariculture (microbes, eutrofization and antibiotics) as well as the production and use of hydrocarbons (oil).

Agriculture is another very contaminating sector, due to the wide use of pesticides, herbicides and fertilizers since the green revolution²³, which has contributed to the impoverishment of ecosystems over the years and to the accumulation of chemical substances in the soil, waters, atmosphere and living beings.

Regarding emission sources, they can be either **specific sources** that are easy to identify -such as dangerous waste deposits, heat and power generation facilities, incinerators and industrial installations- or **scattered sources** like transport, agriculture, muddy sewage, consumption sewage, pharmaceutical products, etc.

The release of these substances into the environment can occur in the forms of liquid, solid, dust, fumes or gas and can be well identified and planned -as part of the production process- or unplanned releases -due to industrial accidents and leakages.

23 Green revolution is the name given to the increase of yields and the introduction of new agricultural technologies in the 60s, i.e. genetic selection and intensive production through the use of fertilizers, pesticides and herbicides.



The **planned release** of chemical substances into the environment can be in the form of the following:

- **Waste:** the leftovers of dangerous products, their containers and any contaminated material used in the productive process -clothes, gloves, sawdust, etc.- that are either placed in dumps, treated in specialized plants or burnt in incinerators. Waste can be also in the form of:
 - **Emissions** released into the environment through chimneys, extraction systems, or ventilation and windows; and
 - **Spillage** through drainages and pipes.
- **Manufactured goods:** During their intended use, manufactured goods may release chemicals into the environment. At the same time, many chemical substances are released into the environment as finished products, including paintings, plastics, cosmetics, electrical appliances and electronics, as well as exhaust fumes from motor vehicles.

There are also **unintentional emissions**, resulting from technical failures or accidents. There are numerous cases of unintentional spills and emissions with perilous consequences for the environment. The effects of only the ten worst accidents involving chemical over the last 40 years have killed or injured an estimated three million people.²⁴ The Bhopal disaster is an

²⁴ Le Monde Diplomatique, Environmental Atlas 2008. If the estimations of the victims of the Chernobyl nuclear accident are considered this figure would climb to 10 million people. Nota Bene: Nuclear / radioactive substances are not covered by conventions and regulations on chemicals and/or hazardous waste. They fall under specific regulations.

emblematic example of widescale and deadly contamination due to accidental emissions of chemicals into the atmosphere (see box 1.12.).

Many substances that have been released for years into the atmosphere or dumped into waters or on land have now proven to be highly toxic and affect the environment and living organisms long after their release and over important distances from the initial contamination site. This is in particular the case of some groups of agrochemicals like DDTs,²⁵ which were used massively in the 1960s and 1970s, and were later banned by many countries when they realized the serious harm DDTs represented not only to rural workers but also to populations exposed through polluted water and land. There is now sufficient evidence concerning DDTs' dangers and some international organizations like WHO have recommended their elimination. Yet, they are still used as insecticides in some countries.

This is the reason why the **Principle of Precaution**²⁶ is of utmost importance (see unit 3 for a definition) when dealing with chemical substances management.

Adverse effects on the environment

An ecosystem is an interrelated network between biotic -living beings- and abiotic -physical and chemical- elements that are permanently in search of balance. All living beings on the planet make an imprint on the environment one way or another. In this complex system of interrelations, human beings are the only ones able to purposefully intervene in nature. All human activity inevitably has an effect on the environment. In this context, human beings have the possibility and the responsibility to appropriately direct their activities in a manner as least harmful as possible for the natural equilibrium of ecosystems.

Throughout the development process of humankind, the pressure on ecosystems have increased due to the growth and expansion of human populations, associated to a greater demand on natural resources in order to meet their needs. Together with new modes of production, especially after the Industrial Revolution, the production and use of chemicals created additional pressure on the environment, which resulted in grave problems.

How is chemical pollution created?

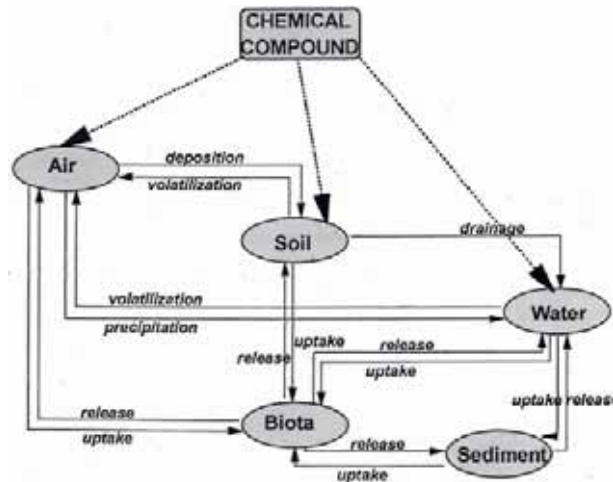
The release of any chemical into an habitat will entail a series of effects and reactions of differing magnitudes, depending on the characteristics of the substance released and the endurance capacity of the ecosystem.

25 DDT (Dichloro-Diphenyl-Trichloroethane) is an synthetic organochloride insecticide of wide spectrum, prolonged and stable action, used in the control of plagues in all types of cultivation since the 1940s. It is listed as a Persistent Organic Pollutant (POPs) (See Module 3, Unit 1, Stockholm Convention on POPs).

26 Principle 15 of the Rio Declaration (1992): "In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation."
(<http://www.un.org/documents/ga/conf151/aconf15126-1annex1.htm>)

Upon release, chemical substances pollute²⁷ the air, soil and water, thus acting on all the components of the ecosystem, including human beings. Many chemicals emitted will persist

Box 1.10. Circuit



Source: UNEP Chemicals Branch
<http://www.chem.unep.ch/Pts/regreports/Translated%20reports/Eastern%20and%20Western%20South%20America%20sp.pdf>

in the environment for years, where they will continually move between the air, water, soil and all living beings or biota. This can be represented as follows (see box 1.10.):

Danger, dispersal and persistence:

Whereas any chemical released into the environment is likely to pollute, all chemicals do not carry the same degree of environmental risk. There are various elements that determine how hazardous a substance can be, including:

- **Stability:** the tendency of a substance or compound to resist chemical reaction (degrading, transforming or combining itself with others substances).
- **Permanence through time:** the tendency of chemicals to remain in the environment for long periods of time, while keeping the same degree of hazard. As they tend to continually move, deposit and move again, certain chemicals have dangerous effects long after their release. This is the case of mercury emitted into the atmosphere during the burning of fossil fuels, or of Persistent Organic Pollutants (POP).
- **The capacity to bio-accumulate:** the capacity chemicals have to accumulate or build up in the tissues of living beings and pass into the food chain. As a

²⁷ The presence of minerals, chemicals or physical properties at levels that exceed the values deemed to define a boundary between "good or acceptable" and "poor or unacceptable" quality, which is a function of the specific pollutant. (GEO4. UNEP, 2007)

consequence, their concentrations can reach high levels at the top of the food chain.

- **The possibility of transference:** Some pollutants can travel long distances, affecting ecosystems that are very distant from the emission sources. For instance, important concentrations of Persistent Organic Pollutants (POP), which had not been produced or used in the region but were carried via water or air from all parts of the world²⁸, have been detected in the Arctic, in animals, in plants and in human beings.

Atmospheric pollution

Chemicals released into the atmosphere reach the water and the soil through precipitation. They can be inhaled by animals or integrated into the food chain through the ingestion of polluted plants. For example, in France, high levels of dioxins²⁹ have recently been detected in farm animals and humans - quite possibly due to the emissions from incinerators that had stopped working more than ten years ago. The chemicals had been absorbed into the soil and different plants used to feed farm animals, which were later consumed by the local population.³⁰

Concerning the effects on human health, data from the World Health Organization are quite explicit: WHO estimates that, 4.6 million people die every year worldwide as a direct consequence of air pollution.³¹

Along with the direct damage to ecosystems and human health, chemicals are part of three exceptionally grave global phenomena linked to atmospheric pollution: acid rain, ozone depletion (reduction of the ozone layer) and climate change (see next sections for further details).

Soil pollution

Pollutants reach the soil either by atmospheric deposit or direct dumping from the source sites (industry, transport, agriculture, etc.). They can be transferred to the air (via volatilization), to water (via drainage) or absorbed by living organisms. They affect not only terrestrial but aquatic ecosystems as well (rivers, lakes, seas).

Old industrial centres, especially in the United States, Europe and the ex-Soviet Union, have a legacy of contaminated industrial and urban lands from past activities. In Europe, there are also many contaminated lands, due to substances such as heavy metals, cyanide, mineral oils or chloride hydrocarbons.³² More recently, the board of directors of La Alumbrera, a gold and copper mining company in Argentina, has been prosecuted by the courts.

28 GEO 4, 2007

29 Dioxins are compounds produced by a burning process that involves chlorine. They are stable, very soluble in fat and not easily biodegradable, they accumulate in soils, organic tissues and can get into the food chain. They are listed as Persistent Organic Pollutants (POPs). (See Module 3, Unit 1, Stockholm Convention on POPs).

30 (Libération, 3 June 2008)

31 State Member ILO (2002), Estimated deaths & DALYs attributable to selected environmental risk factors. http://www.who.int/entity/quantifying_ehimpacts/countryprofilesebd.xls

32 GEO4, 2007

The directors have been accused of filtering hazardous chemicals into the tailings dams and mineral canal over a period of ten years, polluting the soil and underground waters and affecting a vast area. Locals are reporting the death of plants and animals, and the impossibility of using their water wells for human consumption and irrigation.³³

Water pollution

Water resources (rivers, subterranean waters, lakes, oceans) can be polluted through direct dumping from emission sources, soil drainage, and the release of sediments and biota (excretions or decompositions).

Dispersed sources are the most difficult to identify and quantify. Among them, agricultural sewage, containing fertilizers and agrochemicals, are the main source of water pollutants in many countries.³⁴ Other important pollutants are industrial and domestic refuse dumped into rivers as a result of inadequately treated sewage.

Box 1.11. A Tragic Story: The Case of Fire at Sandoz

The fire that started in the Swiss consortium Sandoz, in Basel, on the first November 1986, is an example of contamination of water resources resulting from an accidental spillage. During the fire, 20 tonnes of insecticides, fungicides and herbicides were released into the Rhin river. The poisonous flow reached Holland, 500 km down the river, intoxicating hundreds of tonnes of fish and other aquatic species. More than 20 years after the tragedy, heavy metals like zinc, copper and cadmium, as well as some pesticides and nitrogen are still present.

Source: Swissinfo.ch; 31 Oct. 2006. http://www.swissinfo.org/spa/portada/El_Rin_se_ha_recuperado_del_desastre_de_Schweizerhalle.html?siteSect=105&sid=7212624&cKey=1162321185000&ty=st

Aquatic life has been proven particularly vulnerable to chemical pollution. Indeed, most primary effects appear in aquatic ecosystems. The possibility of transference to the air, sediments and biota -affecting all ecosystems- also influences directly the lives of people by rendering the water sources useless for human consumption, irrigation and other activities.

33 La Capital, 1 June 2008. (http://www.lacapital.com.ar/contenidos/2008/06/01/noticia_5623.html)

34 EPA – Environmental Protection Agency, USA, 2006.

A threat to biodiversity

It is important to point out the impact that pollution has on biodiversity, which is to say, on the variety of living forms on Earth.³⁵ Its significance is broadly recognized as far as its ability for providing fibres and foodstuffs. For example, the recent FAO High Level Conference Declaration about food safety specifically mentions the need to preserve biodiversity as a way of confronting the current global food crisis.³⁶

Equally important as a provider of food, the preservation of ecosystems is essential for insuring the reproductive capacity and life itself. These depend on complex mechanisms like the degradation of refuse by microbes, harvest pollination by insects, climate regulation by the forests, protection of coasts by coral reefs, and the reproduction of aquatic species in the mangroves, among many others.

The alteration of the physical and chemical characteristics of water, air and soil will directly affect all living beings. Different species will react to the same chemical in different ways and to different degrees. A chemical that is highly toxic to aquatic life may be harmless to birds. Some substances have a greater impact on other living organisms than on humans. Some species will suffer malformations, others will see their reproductive capacity altered, and others will simply vanish.

All available evidence points to the fact that a significant phenomenon regarding extinction is currently taking place. Its main difference with previous ones is that it is basically caused by human activity.³⁷ For example, agriculture is the main cause of genetic erosion, species loss and transformation of natural habitats. Given the current tendencies, the growing demand for food production will only intensify the use of agrochemicals, hence aggravating the impact on biodiversity.³⁸

Animals and plants are exposed to chemicals through their functions in the food chain. Each successive step up the food chain causes a stepwise concentration of pollutants, since those tend to accumulate in organic tissue, as is the case of heavy metals (e.g. mercury) or persistent organic pollutants (e.g. DDT, aldrine). For example, a substance found at a certain concentration in plankton will be at a higher concentration in small fish that eat the plankton, higher still in big fish that eat small fish, and higher still in bears or seals that eat big fish. This mechanism is known as **biomagnification** or **bioaccumulation**.

35 Biodiversity or Biological Diversity: the variety of life on Earth, including diversity at the genetic level, among species and among ecosystems and habitats. It includes diversity in abundance, distribution and in behaviour. Biodiversity also incorporates human cultural diversity, which can both be affected by the same drivers as biodiversity, and itself has impacts on the diversity of genes, other species and ecosystems. (GEO4, 2007)

36 FAO High Level Conference on Food Security Declaration (May 2008)

37 Nowadays, 16,000 species have been identified as being in risk of extinction. (IUCN 2006)

38 GEO4, 2007

Box 1.12. A tragic story: the 1984 Bhopal Disaster

On the night of 2 December 1984, over 35 tons of toxic gases leaked from a pesticide plant in Bhopal owned by the Indian affiliate Union Carbide India Limited (UCIL) of the US-based multinational Union Carbide Corporation (UCC).

In the next 2-3 days, more than 7,000 people died and many more were injured. Over the last 21 years, at least 15,000 more people have died from illnesses related to gas exposure. Today more than 100,000 people continue to suffer chronic and debilitating illnesses for which treatment is largely ineffective.

Source: Amnesty International USA: DOW Chemical Company (DOW), Union Carbide Corporation and the Bhopal Communities in India, <http://www.amnestyusa.org/Business-and-Human-Rights/Dow-Chemical/page.do?id=1101668&n1=3&n2=26&n3=1241> (last accessed 14 April 2008)

Box 1.13. A tragic story: in Africa, today

More than 50,000 tonnes of obsolete pesticides have been stockpiled in Africa contaminating tens of thousands of tonnes of soil. While more than 11 million cases of pesticide poisoning occur annually in Africa, few African countries have specialised centres to deal with it. However, the new multi-stakeholder Africa Stockpiles Programme (www.africastockpiles.org) is taking action to clean up obsolete pesticides across Africa and to help prevent re-accumulations.

In addition, the extension of agriculture and corporate marketing have contributed to increased use of agricultural chemicals. In many places, small farmers have abandoned traditional and more environmentally-friendly practices under pressure to engage in the market, to produce improved crops and to increase yields.

In Africa, despite the poor levels of comparable data over the last five decades, trends indicate an increase in the concentration of nitrates and phosphates at river mouths.

*Source: UNEP (2007). Monosson, Emily. "Chemicals use in Africa: opportunities and risks". *Encyclopaedia of Earth*: http://www.eoearth.org/article/Chemical_use_in_Africa:_opportunities_and_risks (last accessed 19 December 2007)*

Global environmental impacts of chemicals

As shown, chemicals affect the water, soil and air resources as well as biodiversity at the local, regional and global levels. In this section, emphasis will be laid on the link between the discharge of chemicals and three global phenomena: acid rain, the reduction of the ozone layer and climate change.

Acid rain, ozone depletion and climate change are among the major global direct and indirect environmental impacts of chemicals. Related polluting mechanisms and situations are among those that show the most far-reaching impacts. They might be interlinked and trigger other mechanisms, which in turn might entail serious environmental consequences.

Acid rain

Chemicals released as smoke and dust from factory chimneys will eventually fall to the earth's surface as dust or in the form of rain. For example, the effects of sulphur and nitrogen oxides released from industrial areas have contributed to acid rain. These substances are emitted into the atmosphere, where they undergo chemical transformations, and are absorbed by water droplets in clouds. The droplets then fall to earth as rain, snow, mist, dry dust, hail, or sleet, even far from the countries where they were emitted. This phenomenon is called acid rain because it increases the acidity of soils, and thus affects the chemical balance of lakes and streams, with a significant impact on the entire ecosystem.

In 1987, acid rain had great repercussions in Europe and North America, causing the acidification of lakes and a decrease in the forest areas, mainly due to the acidification of soils. More recently, a similar tendency has been documented in Mexico and China. Nowadays there is greater control over sulphur and nitrogen emissions in many developed countries, but the risk persists in other regions, especially Asia.³⁹

Ozone depletion: the hole in the ozone layer

The Earth's atmosphere has different layers. One of them is the ozone layer, which contains relatively high concentrations of ozone (O₃), a molecule that is continuously produced and destroyed through natural processes. The ozone layer plays an extremely important role in absorbing the biologically harmful part of the ultraviolet rays that come from the sun. However, the release of chlorofluorocarbons (CFCs) -which have been widely used as refrigerants, propellants, plastic from blowers and cleaning agents for electronic circuitry- has caused a significant reduction in the concentrations of ozone, known as ozone depletion.

The tropic region is the only part of the Earth that does not suffer from ozone depletion. Elsewhere, the reduction in the ozone cap has worldwide implications: the most vulnerable areas are the Polar Regions, particularly Antarctica as well as the inhabited areas of southern Chile, Argentina, New Zealand and Australia. Additionally, the size of the ozone hole -an area almost completely void of ozone- in Antarctica has increased in the past few years, particularly in 2000, 2003 and 2006, though at a slower rate than in the 1980s. The area under the ozone hole varies year to year and it is not possible to say whether it has already reached its maximum size. Chemical climate models predict the recovery of ozone levels in Antarctica to pre-1980 levels could be achieved around 2060-2075.⁴⁰

Awareness of the problem was reflected in the signature/ratification of the Montreal Protocol in 1987. The measures taken under this agreement have enabled significant improvements in the situation: today most of the gases responsible for this phenomenon have been drastically reduced or eliminated. According to some analysts, the principles of common but differentiated responsibility and the financial mechanisms of the agreement are among the factors for its success.

39 WMO and UNEP. Executive Summary- Scientific Assessment of Ozone Depletion: 2006.

40 WMO and UNEP. Executive Summary- Scientific Assessment of Ozone Depletion: 2006.

Climate change

Climate change is considered by some analysts as the greatest challenge in human history. This phenomenon, also called “global warming” in mainstream media, receives a lot of attention and generates significant news flows, as one of the major challenges humankind will have to face over the century, with impacts set to be critical: rising sea level, increased desertification, and melting of glaciers, among others. Initially, climate change is a natural cyclical phenomenon. Yet it has been seriously and adversely altered by human activities, most specifically those involving the emission of so-called **greenhouse gases (GHG)**. The current production and consumption models based on the use of fossil fuels for transport and power generation -vital to both the economy and households- are the main contributors to GHG emissions. Other factors, including land use, deforestation or previously mentioned ozone depletion also contribute to climate change.

As this brief summary demonstrates, the environment is the final recipient of a large quantity of hazardous substances. The debate concerning the sustainable management of chemicals from their production to their final use is much more than a occupational health issue. It represents the struggle for the future of this planet, the quality of life for humankind and the survival of all species.

Processing of chemicals in the environment

There are differing views regarding the capacity that ecosystems have to confront and react towards hazardous chemical substances. Therefore, the question is, how are those chemicals processed into the environment? The response actually depends on a number of complex factors. Yet, in a simplified way, three strategies in particular can help answer that question:

- The environment has a given capacity to **biodegrade** toxic substances -generating new substances that might still be toxic- which means those substances are eventually broken down and can decompose. However, a lot of substances are resistant to decomposition processes.
- Specific ecosystems can **adapt** or **deteriorate**. After undergoing several changes, those ecosystems might show varying levels of loss of diversity, including loss of variety and complexity.
- **Extinction** of a species or group of species could be the last and most catastrophic step that contributes to reduced biodiversity. A species is declared “extinct” when the last individual that belongs to it dies; yet the actual capacity to breed and recover may have been lost long before that point.

Certain levels of contamination or aggression can significantly hinder the capacity of an ecosystem to assimilate, adapt and reproduce. Some of its components or interrelations might also be irreversibly affected. The constant pressure that is currently exerted on ecosystems and the levels of degradation that some of them have suffered have made them extremely vulnerable and have significantly weakened their responsive capacity.⁴¹

41 GEO4, 2007

The environmental problem is also a question of justice

It is necessary to consider and treat the interrelations among the multiple environmental problems such as atmospheric and water contamination, land degradation, climate change and biodiversity loss. Similarly, it is also necessary to connect the environment in the broader scope of issues linked to the vulnerability and welfare of human beings, in particular those suffering from extreme poverty and hunger.

In some cases, those who caused contamination do not suffer from the worst consequences of their irresponsible environmental posture. Instead populations that had nothing to do with it will be the most affected. As can be seen in the previous sections, in several occurrences, chemical contamination affects regions that are very distant from the source of contamination. Likewise, some effects might have a global outreach -such as climate change- and severely affect the lives of human beings and other species that do not bear any responsibility in the polluting emissions.

This unjust distribution of environmental consequences can result from natural processes like wind directions and sea currents or the physical characteristics of a region. However, there are also factors that are directly related to the systems of production and consumption of modern societies. Thus, poor communities in developing countries might find themselves more exposed to the effects of climate change as they are most likely settled on more vulnerable lands, with little -if any- technological, financial and human resources to help them adapt.

In the specific case of chemical contamination, the greater exposure of poorer populations to contamination is very concrete. Even though developed countries are still the biggest producers and consumers of chemical products, in the last few decades the most contaminating production activities have been moved to those countries that are still in the process of development. For example, approximately 60% of the current metal production plants are located in developing countries while developed countries would rather import those metals than produce them.⁴²

This transfer of production has not always been accompanied by means of control or the necessary technological, human or financial resources. This, in turn, increases the risks of further emissions of dangerous chemical products into the environment.

Likewise, within each country, poorer communities are usually more exposed to those risks. Their communities are often situated in industrial areas or near smaller polluting businesses like foundries, mines, agricultural zones and toxic landfills where they are exposed to genuine chemical cocktails. Additionally, most industrial areas and abandoned factories can be found in poor communities where they often serve as shelter for the homeless.

Along with the transference of polluting industries, the transference of hazardous wastes from industrialized countries to developing ones is also common practice. The same happens with some recycling activities such as the dismantling of ships or electronic appliances, both of which have proven highly contaminating.

42 Eurostat 2004

Despite numerous multilateral agreements concerning the movement of dangerous substances, the issue of hazardous waste movement continues to be a crucial problem for the international community. Especially, the Rio Declaration (1992), in its Principle 14, urges countries to “effectively cooperate in order to discourage or avoid the relocation and transference to other countries of any activities and/or substances that cause serious environmental degradation or are considered harmful to human health”,

Although environmental problems affect everybody equally, regardless of their social, cultural or economic conditions, the poorer communities are generally the most affected. Their survival fundamentally depend on the goods and environmental services, which makes them especially sensitive and vulnerable to any changes in the environment.

Chemical contamination and its direct consequences on the quality of the air, water and soil, and its effects on all living organisms severely hinders the capacity for subsistence among many categories of the global population. Indeed, according to UNEP data, natural resources represent 26% of the wealth of the poorest countries and environmental risks account for up to 20% of the total burden of disease in the developing countries.⁴³

Therefore, the environmental issue is not simply a question of technology and financial resources. It is an issue of dealing with a crisis of global characteristics and a challenge to modern societies.

Nowadays is a critical moment, but like any crisis, it should become an opportunity to advance towards a different form of development. The environmental issue is a problem that involves humankind as a whole. The creation of alternatives should therefore necessarily include all segments of our societies. There are obviously economic, environmental, political and ethical reasons to act but, above all, it is an imperative that we guarantee a decent and sound future for the current and next generations.

43 GEO 4, 2007

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UNIT 3: PREVENTION, THE BEST ANTIDOTE TO CHEMICAL EXPOSURE

THIS UNIT WILL ADDRESS THE FOLLOWING QUESTIONS:

1. How do we assess hazards and risks?
 2. How do we ensure safe handling?
-



There are no safe chemicals!

ASSESSING HAZARDS, RISKS AND SAFETY: SAFER HANDLING, WHAT ELSE?

A historical review of chemicals would highlight a set of positive applications and benefits such as medicine, solutions for plague control, detergents, cosmetics, food additives and preservatives, as well as processes in the textile and electronic industries or in the construction sector for example. These benefits arose from the development of chemistry as a scientific discipline, and from the production of chemicals and synthetic materials on an industrial scale.

However, according to ILO, the recent average number of deaths attributable to occupational exposure to hazardous substances is estimated at approximately 440,000 a year (or 20 per cent of all work-related fatalities).⁴⁴ Additionally, hazardous substances may also have harmful impacts on the environment, as indicated in the previous unit.

Environmentally sound management of toxic chemicals encompasses safe manufacture, storage, transport, use and disposal of hazardous chemicals. In other words, it is necessary to develop a proper form of management for chemicals that takes into account the whole life cycle, from manufacture to disposal - **a cradle-to-grave management**. But, how to achieve this?

In assessing hazards and risks, key questions to address would be:

- Can all these negative effects on workers, communities and the environment be avoided?
- Has enough been done yet?
- What should be the role of prevention?

⁴⁴ Ivan D. Ivanov, Igor Fedotov and Monica Wehrle-Mac Devette (2007). "Occupational, environmental and public health". Labour and the Environment: A natural Synergy. UNEP

Whenever individuals or the environment become exposed to hazardous substances, remediation/decontamination measures should be deployed in order to minimize the toxic effects.

However, prevention should be the first step to avoid contamination and exposure of individuals and the environment to toxic products, or, at least, to keep it under maximum “tolerable” levels. Additionally, for most chemicals, there often is no “proof” or “near proof” of adverse effect; yet in the meantime, an even greater number of workers might be exposed. This is why prevention is so crucial to chemical risk management.



It is always better to anticipate, rather than to rely on an after-the-fact approach.

Definitions

A definition of key concepts and terms is necessary:

Hazard: It is the source of danger. It can be defined as the set of inherent properties of a chemical, mixture of chemicals or processes that has the potential to adversely affect the environment or the organisms it contains, during production, usage or disposal.

Risk: It is important to distinguish risk from hazard. Hazard refers to the intrinsic properties of a chemical, whereas risk refers to the chance or probability that the chemical will cause an adverse health or environmental effect.

If there is a high risk that a certain chemical will cause cancer to exposed workers, then it is very likely that some of those workers will develop cancer. If the risk is low, then it is less likely that the workers will develop cancer. However, even if the risk of some health effect is low, the chemical in question is still a hazard.

Depending on the circumstances, a “low risk” may be acceptable to the people exposed. Determining the “acceptable risk” is part of the process for setting safety standards. “Setting safety standards” is not a scientific but a political issue. Therefore, it is important that workers have a say in their definition.

Risk assessment involves **identifying the origin of the hazard** (the chemical of concern, for instance, and its adverse effects, target populations and conditions of exposure), **characterizing the risk**, **assessing exposure** (by modelling, measuring or monitoring), and **estimating the risk**. Thus, it consists of identification and quantification of the risk resulting from a specific use or occurrence of a chemical, and takes into account the potential harmful effects on individuals of using the chemical in the manner and amount proposed, as well as all possible routes of exposure.

Risk management covers the whole range of actions taken to prevent, minimize or otherwise control specific risks posed by a certain chemical or situation. This also refers to the search

for **substitutes** for problematic chemicals, or for new and different processes to avoid the use of chemicals.

In this regard, the notion of **safety** is even more difficult to define than risk or hazard. The safety of a chemical, in the context of human health, is the extent to which a chemical may be used in the amount necessary for the intended purpose, with a minimum risk of adverse health effects. It can also be defined as a “socially acceptable” level of risk. But it is usually unclear which part of society is judging the risk. Workers that are exposed to the risk are likely to be more concerned about the safety of a chemical than others are. Therefore, it is very important to question statements such as “this chemical is safe” or “there is a high level of safety when using this chemical”. Safety is a subjective concept, which needs to be properly defined in practice.

The next module will focus on safety in the workplace.

PRECAUTIONARY PRINCIPLE

As part of the prevention culture, the **precautionary principle** is a key driving notion.



“It is a truth very certain that when it is not in our power to determine what is true, we ought to follow what is most probable.”

René Descartes (1596-1650)

With origins in the late 1970s, the “precautionary principle,” is a response to the environmental and human health impacts caused by rapid industrial growth and the inadequacies of earlier pollution control legislation. In the context of chemicals management, the precautionary principle responds to:

- The complexity of environmental health problems;
- The paucity of information and subsequent uncertainty about cause-effect relations; and
- The slow pace of testing and government decision making.

At its core, the principle calls for preventive, anticipatory measures when an activity raises threats of harm to human health, the environment, or wildlife, even when some cause-and-effect relationships are still not fully established scientifically.

The precautionary principle is rooted in international policy and legally binding agreements dealing with high stake environmental concerns that involve scientific uncertainty. From the Report of the 15th Session of the UNEP Governing Council (1989), to the Rio Declaration on Environment and Development (Principle 15), the Stockholm Convention on POPs, the Ozone Layer Protocol, the Climate change Convention, the London Convention on

Ocean Dumping, the OSA and North Sea-related Decisions, the UN Fisheries Agreement, and many other multilateral environment or natural resource agreements, the principle of precaution has gained widespread international acceptance as a guiding principle for decision making.

Although there is no formal agreement on a universal definition that covers all situations, acceptance of the precautionary principle nonetheless reflects a significant paradigm shift in the realm of “environment, human health and development” decision making.

The precautionary principle is a moral and political principle, which states that if an action or policy might cause severe or irreversible harm to the public, in the absence of a scientific consensus that harm would not ensue, the burden of proof falls on those who would advocate taking the action.⁴⁵

This is the reason why many workers and trade unions demand that the principle of “not assessed, not used” be enforced. Precaution is about taking protective decisions based on the best available evidence.

Box 1.14. Nanotechnology, nanomaterials and precaution

Nanotechnology is a rapidly emerging technology that is expected to result in major changes across many industry sectors. This may bring many advances to society and benefits for the environment, but also poses new challenges, especially to health and safety.

To date discussions on the potential benefits of nanotechnology have mostly taken place separately from discussions on the potential risks of nanomaterials to human health and the environment. In the context of prevention, it is important that the precautionary principle be taken into account in assessing the development of these emerging approaches and processes.

Source: Sustainlabour, 2008

45 Raffensberger C, Tickner J (eds.) (1999). Protecting Public Health and the Environment: Implementing the Precautionary Principle. Island Press, Washington, DC

ALTERNATIVES: SUBSTITUTION PRINCIPLE

Substitution is one of the most important preventive techniques, given that it seeks to eliminate a certain risk at its source, through the implementation of significant changes in the productive process.

These changes can be grouped in three levels:

- Substitution of an auxiliary substance or primary resource for another without affecting the productive process,
- Substitution of equipment and procedures without affecting the production process, and/or
- Substitution of an auxiliary substance or primary resource in an equipment, with changes in the production process.

UNIT 4: GREENING OUR CHEMICAL WORLD

THE UNIT WILL ADDRESS THE FOLLOWING QUESTIONS:

1. Is it possible to develop a different chemistry?
 2. What is "green" chemistry?
-

It is often argued that the consequences of hazardous chemicals on public health and the environment should be understood as a necessary part of the development of so-called modern societies, which bear "socially accepted" side effects.

Yet, is the current mainstream chemistry known thus far the only possible way forward? Is there no possibility to move towards more sustainable, clean production models? Rather than the existence of chemistry itself, as it has been largely practiced over the past decades, the question relates to the types of chemicals, their roles, as well as the principles and criteria that should provide the basis for deciding which chemicals should be produced and to what ends.

Chemistry is the basis of life: we breathe O₂ (oxygen), we drink H₂O (water), we expel CO₂ (carbon dioxide), and when we die we become CH₄ (methane) or if cremated turn into PCDD and PCDF (dioxins and furans). The development of chemistry should thus be compatible with the development of life and the protection of the environment.

WHAT ARE THE LIMITS OF THE CURRENT CHEMISTRY?

Two problems can be identified in today's chemistry, among others: **occupational exposure and human health risks**, and **environmental pollution**. The relationship between social, occupational and environmental risks is increasingly recognized and integrated in the decisions regarding the production and use of chemicals.

At the same time, other significant circumstances affect even the viability of the chemical industry in a relatively near future. The **dependency of current chemistry on fossil fuels** requires close attention: an overwhelming volume of products and synthetic materials are made from organic compounds based on fossil materials, primarily petroleum. Therefore, the variation of prices and production of petroleum is set to affect the chemical industry. It is therefore legitimate to wonder whether we are moving from a **peak oil scenario** to a **peak chemicals scenario**.⁴⁶

46 Based on Mestres (2006), Hacia una producción química sostenible. University of Valencia.

It is important and necessary to identify alternative sources of organic renewable materials to ensure that the chemical industry remains the supplier of products and materials for the human wellbeing.

The production and use of chemicals have not only expanded quantitatively, but also geographically. Africa, but also Latin America and Asia are becoming dumping grounds for chemical wastes, while chemical industries are also relocating increasingly into these countries, where there is less fiscal and regulatory oversight and pressure.

It is expected that there will be a significant shift in the production of chemicals from OECD countries to non-OECD countries. It is estimated that the developing world will increase its share from 23 per cent of global demand for chemicals and 21 of production in 1995 to 33 and 31 per cent, respectively, by 2020.⁴⁷

It is essential to strengthen chemicals regulations nationally and internationally. It is also necessary to promote development and to base production on cleaner and safer technologies. The strengthening of chemicals regulation and the promotion of cleaner and safer technologies will be the best preventive measure to anticipate and avoid occupational and environmental exposure to hazardous substances as well as possible accidents.

GREEN CHEMISTRY IS THE KEY! CAN THE DOOR BE UNLOCKED?

Taking into account that all toxic chemicals are dangerous, and that there is no possibility to eliminate risk completely, but at least to reduce it as much as is feasible, it seems logical to develop a chemistry which is as little harmful as possible. Substitution of products and processes is a very valuable and necessary component in daily practices and production, and should be promoted.

However, adopting a chemical-by-chemical/individual substance substitution approach is too slow, due to the large number of chemicals already on the market. It needs to be accompanied by the promotion of a new conception of chemistry, a sustainable chemistry or **green chemistry**.

Green chemistry is based on the application of a series of principles by which the use or generation of hazardous substances is reduced or eliminated in the design, manufacture and application of chemical products,⁴⁸ by using renewable raw materials, manufacturing products that are non-toxic and biodegradable, and avoiding waste. Moving forward to a different chemistry based on imitation of nature, or biomimesis, must be part of that "green" future.

47 Monosson, E. (2007). "Chemicals use in Africa". Encyclopaedia of Earth http://www.eoearth.org/article/Chemical_use_in_Africa (last accessed 19 December 2007)

48 Anastas, P. T. Warner, J. C. (1998). Green Chemistry: Theory and Practice, p.30. Oxford University Press, New York

Box 1.15. Green Chemistry research

Based on 12 principles, the Green Chemistry approach was developed by Doctors Paul Anastas and John Warner:

1. **Prevention:** It is better to prevent waste than to treat or clean up waste after it has been created;
2. **Atom Economy:** Synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product;
3. **Less Hazardous Chemical Syntheses:** Wherever practicable, synthetic methods should be designed to use and generate substances that possess little or no toxicity to human health and the environment;
4. **Designing Safer Chemicals:** Chemical products should be designed to effect their desired function while minimizing their toxicity;
5. **Safer Solvents and Auxiliaries:** The use of auxiliary substances (e.g., solvents, separation agents, etc.) should be avoided wherever possible and innocuous when used;
6. **Design for Energy Efficiency:** Energy requirements of chemical processes should be recognized for their environmental and economic impacts and should be minimized. If possible, synthetic methods should be conducted at ambient temperature and pressure;
7. **Use of Renewable Feedstocks:** A raw material or feedstock should be renewable rather than depleting whenever technically and economically practicable;
8. **Reduced Derivatives:** Unnecessary derivatization (use of blocking groups, protection/deprotection, temporary modification of physical/chemical processes) should be minimized or avoided if possible, because such steps require additional reagents and can generate waste;
9. **Catalysis:** Catalytic reagents (as selective as possible) are superior to stoichiometric reagents;
10. **Design for Degradation:** Chemical products should be designed so that at the end of their useful lives they break down into innocuous degradation products and do not persist in the environment;
11. **Real-time analysis for Pollution Prevention:** Analytical methodologies need to be further developed to enable real-time, in-process monitoring and control prior to the formation of hazardous substances; and
12. **Inherently Safer Chemistry for Accident Prevention:** Substances and the form of a substance used in a chemical process should be chosen to minimize the potential for chemical accidents, including releases, explosions, and fires.

Source: Anastas, P. T.; Warner, J. C. (1998) *Green Chemistry: Theory and Practice*, Oxford University Press: New York, p.30.

The proposal of a sustainable chemistry goes hand-in-hand with the need to develop sustainable products, based on **clean production**.

Imagine, then, a chemical that:

- Does not accumulate in the environment or in our bodies,
- Does not present toxicity - neither to human beings nor to the environment,
- Is based on renewable resources,
- Minimizes the use of energy and resources,
- Whose products can be reused, recycled or composted at the end of their lives, and
- That produces necessary and useful products and safe jobs.

Box 1.16. Clean Production

Cleaner Production is the continuous application of an integrated preventive environmental strategy to processes, products, and services with a view to increasing overall efficiency, and reducing risks to humans and the environment. Cleaner Production can be applied to the processes used in any industry, to products themselves and to various services provided in society (UNEP, 2001).

- **For production processes**, Cleaner Production results from one or a combination of raw materials, water and energy; eliminating toxic and dangerous raw materials; and reducing the quantity and toxicity of all emissions and wastes at source during the production process;
- **For products**, Cleaner Production aims to reduce the environmental, health and safety impacts of products over their entire life cycles, from raw materials extraction, through manufacturing and use, to the "ultimate" disposal of the product; and
- **For services**, Cleaner Production implies incorporating environmental concerns into designing and delivering services.

Source: UNEP. Sustainable Production and Consumption Branch. "Cleaner production: key elements" http://www.unep.org/pc/cp/understanding_cp/home.htm#definition (last accessed 19 December 2007)

Is that a fantasy? Or can it be the reality of our future. Apart from formulating objective and general strategies, it seems necessary to answer the fundamental question of whether it is technically feasible to develop and implement green chemistry and to establish clean production systems.

Numerous chemical products are already being developed by major companies according to these principles. As they also represent significant new economic opportunities, consumers and clients should urge companies to adopt widely green chemistry. Yet, it is important to guarantee that the products of green chemistry do not have adverse effects on workers' health.

It is true that many technical questions remain unsolved. Nonetheless, it is difficult to find answers when the resources allocated to research and development as well as impact assessment are not sufficient.

The political will to invest in innovation and research, to adopt regulatory frameworks that prioritize clean production and green chemistry incentives, and to promote capacity development for appropriate action are some of the doors that need to be unlocked.

Trade unions and workers, the first victims of hazardous chemicals, can and need to push these doors, while looking for alliances with the scientific and research community, and the private sector to obtain collectively a stronger impact.

Green chemistry is the key to the door to a sustainable path forward.

WHERE TO GET MORE INFORMATION?

Sources of information to identify substances (last accessed 14 April 2008):

- International Chemical Safety Cards <http://www.ilo.org/public/english/protection/safework/cis/products/icsc/> or http://www.unece.org/trans/danger/publi/unrec/12_e.html: for essential information about chemicals' physical properties, as well as health and safety information on the use of chemicals at the "shop floor" level by workers and employers in factories, agriculture, construction and other work places
- TOXNET <http://toxnet.nlm.nih.gov>
- Hazardous Substance Database (HSDB) <http://toxnet.nlm.nih.gov/cgi-bin/sis/htmlgen?HSDB>
- Pesticide Action Network Database <http://www.pesticideinfo.org>
- ChemIDplus <http://chem2.sis.nlm.nih.gov/chemidplus/chemidlite.jsp>
- European Chemicals Bureau <http://ecb.jrc.it/existing-chemicals/>
- RISCTOX database: Contains information in Spanish on the health and environmental risks of over 30 000 chemicals - <http://www.istas.net/ecoinformas>

MODULE 1 REFERENCES

Official websites:

- International Labour Organization. "Safe work" <http://www.ilo.org/public/english/protection/safework/intro/>

Documents:

- ILO. International Labour Office. "Programme on Safety and Health and Work and Environment. International Chemical Control Toolkit" http://www.ilo.org/public/english/protection/safework/ctrl_banding/toolkit/main_guide.pdf
- ILO. "International Occupational Safety and Health Centre of Information: Basics of chemical safety" <http://www.ilo.org/public/english/protection/safework/cis/products/safetytm/toc.htm>
- ILO. International Occupational Safety and Health Centre of Information. "Chemical safety training modules" <http://www.ilo.org/public/english/protection/safework/cis/products/safetytm/index.htm>
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